WATER IMMERSION REDUCED GRAVITY SIMULATION

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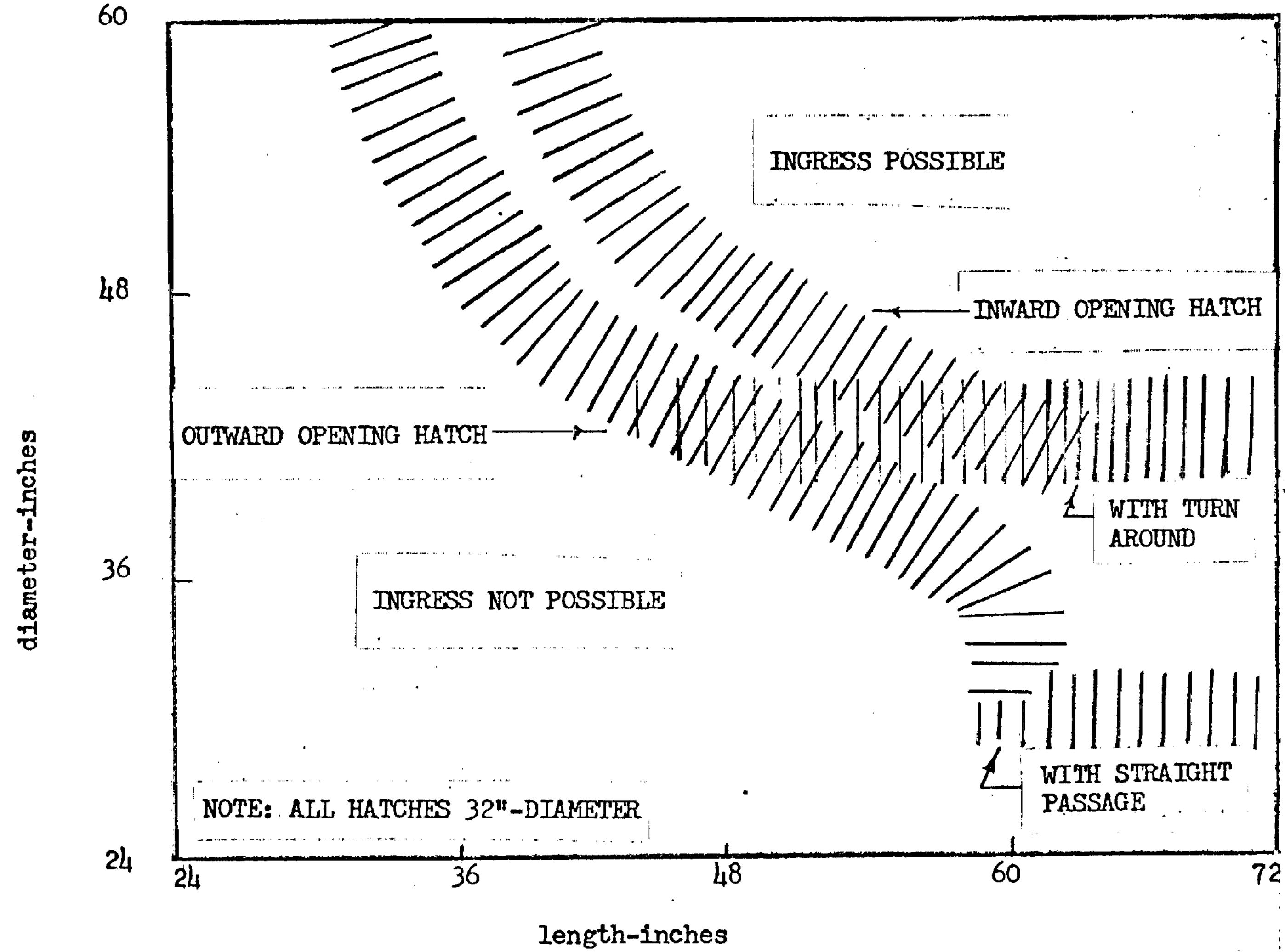

Figure 9.- Airlock Dimensional Requirements for a Single Pressure Suited Subject Derived from an Experimental Man-system Integration Study by Neutral Buoyancy Water Immersion Simulation Techniques.

ABSTRACT

A technique for simulating zero and partial gravity performance of an astronaut in a pressurized suit by complete water immersion has been developed and employed to examine several extravehicular task areas in space. The technique allows the pressure-suited subject to move in six degrees of freedom unencumbered by connecting supports, simulating his biomechanical performance in weightless space.

Experiments have been conducted which illustrate the usefulness in examining the astronaut's capability to execute extravehicular work procedures, developing man-system engineering data, and as a training system. Several extravehicular task areas have been examined by use of the simulation technique including ingress-egress through airlock systems, manual self-locomotion, manipulation and maintenance tasks, and assessment of rescue procedures. Although limited in the study of rapid translatory tasks by the drag and damping effects of the water, the technique permits a perceptual equivalent simulation of complex manipulative tasks in real time. A description of the test procedures, equipment, and several typical tests is provided.

INTRODUCTION

Background

The success of man's endeavor to explore the universe depends on the development of advanced technology to accomplish this goal in an economical, timely manner within the limitations of our national economy. Ten years ago manned space flight was only a dream in men's minds, but today it is rapidly becoming a reality with the application of technology from many diverse fields. Recent flight experience in extravehicular operations has shown the need for accelerated development of human factors information well in advance of flight tests to determine the astronaut's biomechanical capabilities and performance in the weightless environment, determine his physiological and psychological limitations, develop pertinent man-system integration data and to provide training to insure the success of the mission tasks.

Although the principal physical factors of weightlessness are well understood, no totally satisfactory "ground-based" simulation technique exists for developing this information. However, much valuable human factors data can be economically obtained for the zero gravity tractionless environment of space by various simulation techniques including Keplerian trajectory aircraft flights, cable suspension and counterbalanced systems, air bearing platforms, and neutral buoyancy water immersion techniques. Each of these simulation modes has inherent advantages and limitations. The aircraft testing closely approximates the zero gravity condition of space flight, however, it is limited to test durations of 15 to 30 seconds and the tests are often negated by the random motion of the aircraft.

Cable suspension systems are economical to build but restrict the degrees of freedom in which the test subject can operate and prevent operation in confined spaces. Counterbalanced systems using yokes and gimbals permit operation in three to six degrees of freedom, but have the disadvantage of large counterbalancing masses attached to the test subject and are highly sensitive to changes in center of gravity. The water immersion technique allows operation in six degrees of freedom even in confined spaces, but is limited in the study of the total dynamics of maneuvers by the hydrodynamic damping and drag forces. Each of these simulation means is superior in studying certain operations and often a combination of two or more are complementary to one another in performing a more complete study.

Early efforts to utilize neutral buoyancy techniques to simulate the condition of space were used to develop physiological data are reported by (Knight, 1958), (Graybill and Clark, 1960), (Graveline, 1961), (Beckman and Coburn, 1961), (Stone and Letko, 1964), and others. Later investigators began to examine the use of water immersion techniques to simulate the external motion performance in weightless space as reported by (Pierce and Casco, 1964), (Trout, 1964), (Loats and Mattingly, 1964), (Bulk, 1964), (Wolf, 1964), (Trout, Loats, and Mattingly, 1966), (Morton, 1965), and others. These efforts led into the use of pressurized space suits with the subjects balanced to neutral buoyancy.

The water immersion simulation technique, which will be discussed in this paper, provides certain unique advantages. It permits a neutrally buoyant subject to operate in six degrees of freedom for long periods of time unrestrained by connecting lines, counterbalancing masses, yokes, or gimbal systems. It provides for total support of the body appendages and is relatively insensitive to changes in center of gravity. Weight and balance techniques have been worked out to achieve neutral buoyancy in all planes. The simulation is not time limited since an entire set of extravehicular procedures can be carried out without interruption.

This technique is limited by three factors:

Drag, damping effects.

Necessity for added mass due to ballast requirements.

Attitude stability characteristics imposed by water depth-pressure relationships and the nonrigid suit.

The most obvious limitation imposed by the water immersion simulation mode is due to the frictional drag associated with movement through the water media. The drag produces several undesirable effects relative to true weightless performance.

Linear and rotational velocity are rapidly attenuated, thus limiting the range of motions.

The drag of the water can be utilized by the subject to provide minor body reactions which would not be possible in true weightless environments.

Since the subject is still gravity oriented within the pressure suit, there is no simulation of the internal physiological effects of weightlessness on subject performance. However, for certain task simulations requiring interrelated processes such as airlock ingress-egress, internal effects of weightlessness on subject performance is of only secondary importance. For this class of experiments, the main desiderates are satisfied by the simulation of the external effects of weightlessness; that is, lack of traction and support. These requirements are fulfilled by the water immersion mode. Considering the variation of this technique from a true weightless environment, the selection of tasks to be performed will be governed by the major classes of body movement required in their performance. These types of movement are postural, transport, and terminal.

The first major class of movement is that of postural movements which are relatively large motions required to regulate the orientation of the body in relation to some reference. In weightlessness, the gravity orientation cue is absent and the postural movements are attendant such external references as imposed inertial fields, visual reference, etc. Task selection should take into account the fact that gravity cues are still present within the suit. The physiological aspects of normal gravity are still present and produce reference to which the subject tends to orient himself.

In general, tasks involving postural movements should be oriented to accommodate the tendency to seek out the vertical position as the normal working or maneuvering position to cancel out the adverse physiological effects and provide an acceptable reference frame.

The second type of movement, those of the transport class, involve movements which translate the body through space. These movements are intrinsically organized in relation to the bilateral symmetry of the body and are integrated with the postural movements which function to modify and direct the transport movements.

Tasks, which impinge upon this class of movement, should be limited to low-velocity, near-static tasks in which the movement is not of long duration. Perhaps one of the best examples to illustrate this point involves the techniques of soaring. This type of maneuver involves relatively high linear velocity and long duration. Tests performed aboard the zero gravity aircraft indicate that if launch thrust did not pass through the body's center of mass,uncontrolled rotation could result. The inflated full-pressure suit did not allow the subject sufficient mobility and kinesthetic feedback to accomplish the launch and soar without some uncontrolled rotation.

The same type of task performed in the water immersion mode did not produce the uncontrolled rotation. The large linear and rotational velocities were rapidly attenuated by the drag effect of the water media.

The third type of movement involves the manipulative movements involving the terminal elements of the body; for example, limbs, fingers, and head. Movements in this category are not significantly affected by the water media.

The terminal elements, generally, involve low-velocity movements in which the drag forces are negligible compared to the suit forces.

The selection of tasks should take into consideration the desirable and undesirable aspects of the tasks with respect to the type of movements involved. Below are listed typical tasks adaptable to water immersion simulation and the reasons for their choice:

Spatially restricted tasks - Including ingress-egress through passageways, hatches, and airlocks where the velocities are low and traction is available.

Force application tasks - Including torque application where body movements are restrained and where body movements and position do not change rapidly.

Manipulative tasks - Including assembly, alinement, attachment of equipment where the drag forces on the body limb movements are relatively small.

Extravehicular tasks which have been examined by water immersion simulation mode include ingress-egress through passageways, hatches, and airlocks; astronaut force measurements; extravehicular manual locomotion by hand rails, handholds, and cables; rescue operation through airlock systems; cargo transfer functions; and manipulation of equipment. The simulation mode has been used to study feasibility and develop procedures in support of current extravehicular flight tests. Man-system integration studies have been made of airlock dimensional requirements for future flight tests. Biomechanical data are being developed to assist in the development of advanced pressure suits. Measurements are being made of the astronaut's energy expenditure by metabolic means during the simulation to better understand the astronaut's work output capabilities.

The water immersion simulation mode has been used as a training technique for Gemini XII, the effectiveness of which has not yet been totally determined.

The current paper will discuss in greater detail, the simulation procedures and equipment, safety procedures, and some of the tasks to which the technique has been applied.

EQUIPMENT AND PROCEDURES

General

Water immersion simulation techniques have been used for obtaining human factors information relative to intravehicular and extravehicular operations in space including the astronaut's biomechanical and physiological performance, man-system interfaces, and operational procedures.

Pressure Suit Operation

During the study of intravehicular operations for determining operational modes, self-locomotion, and control manipulation, the test subjects were dressed with normal clothing or divers wet suits and provided with either scuba or hookah breathing systems. On the other hand, for the simulation of extravehicular operation, the use of pressurized space suits has been deemed necessary. The discussion throughout the remainder of this paper will deal only with those simulations requiring pressurized suits.

Two approaches have been used to simulate the pressure suited astronaut working in weightless space by water immersion techniques. First, the water-filled suit as described by (Wolf, 1964) and (Dean, Langan and Erickson, 1965), and the air-filled suit as described by (Trout, 1964) and (Loats and Mattingly, 1964).

Early attempts to use the water-filled suit used them in an unpressurized condition or provided a neck seal to provide water inflation of the torso of the suit to about 1 psi, while providing for the subject's breathing with a scuba apparatus through the open face plate of the helmet. Breathing difficulties resulted from pressurizing the suit torso above the pressure at the face. Additional refinement of the water-filled suit system led to a system whereby the suit was pressurized to 3.5 psi and a breathing system provided in the closed helmet, as illustrated in the diagram of figure 1. The breathing system provided for the subject's facial area to be sealed off and maintained at a pressure slightly above the torso. Ballast is provided on the suit to achieve neutral buoyancy.

The air-filled pressure suit system is illustrated in the diagram on figure 2. High-pressure air from a supply source enters the system through a first-stage regulator which reduces it to about 90 psi. The pressure is reduced to about 5 psi in a second-stage regulator. A demand regulator in the suit helmet provides for a flow of air into the facial area when the subject inhales and closes whenever the subject exhales. A pressure relief valve in the torso of the suit maintains a preset pressure within the suit. To achieve neutral buoyancy, lead weights are added to the torso of the suit and the subject is balanced in pitch and roll by fastening weights to the body appendages and adjusting the torso weights around the suit. For the U.S. Navy Mark IV suit as shown in figure 3, between 70 and 90 lb of ballast is required to achieve neutral buoyancy. Simulation utilizing the Gemini G4C suit used a constant flow of air into the suit through an umbilical, and a pressure relief valve on the exhaust was used to maintain suit pressure with a similar ballast system as illustrated in figure 4.

Comparison of the water-filled and air-filled modes of operation of pressure suits in neutral buoyancy simulations indicate that the complexity of the two systems is about equal. The added weight for ballast is nearly equal for the two systems if the water contained in the suit is considered part of the ballast. The added weight in either system tends to increase the inertia of the suited subject. Due to the incompressibility of water and viscous flow of water within the water-filled suit, the suit is less mobile when limb movements change the internal volume of the suit.

The air-filled suit does not put the subject's body in direct contact with the water; however, the water-filled suit provides somewhat more uniform support of all parts of the body. Because water pressure increases with depth, the differential pressure across the air-filled suit varies between the head and feet when the subject is immersed in an upright position.

Although contention exists as to which system is best, the authors have chosen the air-filled suit system since they believe that it affords greater safety to the test subject and more nearly approximates the pressure suit mobility in space. The tests described in the remainder of this paper were conducted with the air-filled suit system.

For tests at gravity levels of 0.08 and 0.16g, a similar technique is employed except that an appropriate extra weight is added to accomplish a proper net negative buoyancy.

Although the faceplate of the helmet acts as a large concave lens causing visual distortion when immersed in water, visual accommodation and convergence by the eyes are readily accomplished by the test subjects. Objects appear to be farther away and a slight crossed vision results from the position of each of the eyes in relation to the curvature of the faceplate.

Safety Procedures

Unplanned emergencies, similar to those possible in actual space conditions, can and have happened during water immersion tests. Two of the most common emergencies occurring are rupture of the pressure suit envelope and the subject's becoming trapped in a confined space. Ruptures have occurred in the hand, foot, torso, and helmet areas of the pressure suits causing immediate decompression with subsequent termination of operations. No interruption of the subject's breathing has occurred since large quantities of water were prevented from entering the suit by the incoming air.

The subject was frequently trapped by being snagged while entering or leaving the test mockup. This usually took the form of looping an airline or suit strap around equipment protuberances, lifting eyes, hand, or foot holds.

Many of the emergencies which occurred can be eliminated by proper design of mockups and the use of equipment in good condition; however, emergencies may arise for which the test crew must be trained to handle.

Listed below are some of the major procedures used to avert and handle emergency situations during water immersion tests:

(a) Each test subject and safety man is previously trained in full-pressure suit operation, is a fully trained scuba instructor, and is required to induce suit/helmet failures while in a submerged state to determine efficiency of prearranged rescue procedures.

(b) Each pressure suited subject is provided with two qualified scuba-equipped safety men, a primary and a secondary, while working in a submerged state.

(c) Additional scuba equipment and a surface safety line is kept near the safety men in event of suit failure, to provide life support and rescue.

(d) Unnecessary protuberances and sharp edges are eliminated from the mockups.

(e) Visual inspection of all equipment is made before each test.

(f) The mockups requiring internal operations are bisected and hinged to provide quick access in event of emergency.

Test Facility

For the tests reported in this paper, a swimming pool approximately 36 feet by 79 feet by 11 feet maximum depth was generally used. Testing with mockups was carried out in the deep end of the pool, while suit balancing and checkouts were performed in the shallow end.

Although the use of a swimming pool for testing is advantageous from the availability standpoint, there are several disadvantages. Greater depth is needed to prevent interaction of the test subjects with the bottom and surface. The size and geometry of mockups is limited. Photography and related lighting conditions are generally poor, and provisions for observers are inadequate unless external viewing windows are provided. Control of water clarity is of utmost importance for good photographic coverage of tests. Conditions have been encountered where micro-organisms multiply at rates wherein water clarity cannot be maintained by even the better filtering systems. In addition, small bubbles can be retained in the water by surface tension,reducing clarity. To prevent these conditions, growth retardants, chemical treatment of the water, and frequent cleaning of the pool surfaces are necessary.

Mockups and Test Hardware

For man-system integration tests, mockups should be representative of the entire interface of the area in which the subject is working. Figure 5 represents one of the airlock configurations used in ingress-egress tests reported in this paper, while figure 6 presents a photograph of the mockup of the Gemini vehicle and accompanying service module used in evaluation of the Gemini extravehicular operations.

During the water immersion studies to assess the operational characteristics and man-machine relationships for ingress-egress performance, the airlock, figure 5, was submerged in approximately 10 feet of water and suspended approximately 18 inches above the pool floor. The cylindrical section of this airlock, constructed of heat-formed acrylic clear plastic, was 48 inches diameter by 6 feet long, bisected and hinged along the horizontal centerline for quick removal of the test subject in event of emergency. An outward opening hatch 32 inches in diameter was contained in the bulkhead at one end and an oval inward opening hatch 28 inches by 36 inches at the opposite end. Similar cylindrical airlocks having diameters from 24 inches to 60 inches with a movable interior bulkhead were used in a man-system integration study of minimum airlock dimensions for the pressure suited subject in the neutrally balanced state.

The mockup illustrated in the photograph of figure 6, of the full-scale Gemini capsule and service module, was approximately 28 feet long and 11 feet in diameter, supported from the bottom of the pool.

The size of mockups is limited by testing facility size and handling considerations. In addition, mockups and related hardware can be made neutrally buoyant to simulate their reaction when disturbed by the test subject during his operations. Thus, a partial or total field can be set up where necessary.

TYPICAL TESTS AND RESULTS

General. Bearing in mind that the purpose of simulation is to provide a tool for the development of knowledge and proficiency where acquisition from the original source would be impractical, the water immersion simulation has been investigated for application to several possible extravehicular areas. These include ingress-egress, extravehicular self-locomotion, local personnel rescue, crew and cargo transfer, maintenance and assembly, and the development of procedures. The scope of this paper does not permit discussion of all this work, however, some typical tests and the data derived from them will be discussed.

Ingress-egress. Ingress-egress operations are essential to the performance of manned extravehicular tasks in space. Either the spacecraft cabin must be depressurized or an airlock provided for access to the spacecraft exterior. For advanced space missions with larger vehicles where a large number of extravehicular operations are required, an efficient, well-designed airlock system is necessary. To optimize airlock design, man-system engineering data and a knowledge of operational procedures for zero-gravity conditions is required. It was apparent that data from 1g ground conditions was not applicable. Therefore, an effort was undertaken to develop the necessary data and procedures by weightless simulation.

A survey of simulation techniques indicated that air bearing platforms, cable systems, and gimbal or yoke suspension systems did not permit realistic operation in confined spaces. The Keplerian trajectory aircraft flights gave zero-gravity working times of 20 to 30 seconds, which made it impossible to complete operations without interruption. Simulation by water immersion techniques, although not well developed at the time, appeared to be a promising method for determining the ingress-egress capabilities of the pressure-suited astronaut, assess the operational characteristics, and man-machine relationships for advanced mission airlock concepts. Therefore, such a program was undertaken utilizing water immersion techniques, and several comparative tests made by zero-gravity aircraft to examine the validity.

Figure 5 embodied what was considered to be representative geometry for an airlock which could be operated manually by a single-suited subject. The airlock was 4 feet in diameter by 6 feet long. In a pressurized anthropometric space suit, manual operation by a single subject implies that the subject directly actuates both inboard and outboard hatches, controls, and requires that he execute a turnaround maneuver to close the hatches. Figure 7 presents a sequence photograph of a typical ingress-egress operation through this airlock utilizing water immersion techniques. In order to eliminate lines and hoses for operation through operable hatches, the subject is equipped with a 70 cubic foot capacity air bottle on his back which provides for breathing and suit pressurization.

Sequence (a) figure 7 shows the pressure-suited subject operating the hatch actuator handle while sequences (b) and (c) show him entering the airlock after opening the hatch. The hatch in this case opens inward. Such a design may be required for safety and/or structural reasons. Sequences (d) and (e) show the turnaround required to close the hatch through which the subject has entered, sequence (f). An additional turnaround is then required to open the hatch at the opposite end of the airlock sequence (g). Tests by the pressure-suited subject indicated that he was capable of performing the turnaround in the 4-foot diameter airlock with some difficulty, but that the six-foot length was more than adequate. Sequence (h) shows the subject making egress from the outward opening hatch at the opposite end of the airlock.

Tests of this nature allow us to examine the capabilities of the astronauts, develop procedures for operation, obtain information relative to systems design, develop more realistic time-line analyses for space operations, and provide insight into the feasibility of other extravehicular operations.

The biomechanical measurements of three of the major limb movements as a function of time during a typical ingress-egress operation through the above airlock are presented on figure 8. Measurement of degree of deflection and frequency is a qualitative indication of energy expenditure in the pressurized suit. A more complete compilation of biomechanical information for planned extravehicular operations should be of value in the development of advanced pressure suits.

A man-system integration study of airlock dimensional requirements was performed under simulated zero-gravity conditions with the use of transparent airlocks having diameters of 24 in., 30 in., 36 in., 42 in., 48 in., and 60 in. A movable bulkhead was used in each of these to determine the minimum length into which the pressure-suited subject, as shown on figure 7, could ingress. Illustrated on figure 9 is a summary of the results of this study. Below the lower shaded curve, ingress was not possible for those airlock diameter-length combinations shown for an outward opening hatch. Straight passage was possible through a cylindrical tunnel of about 30 in. or more as illustrated by the lower horizontal curve. The curve marked inward opening hatch shows the approximate minimum diameter-length combinations for possible ingress into this configuration. Turnaround maneuvers within the airlock became possible at diameters of 42 in. or greater. An airlock can be too large by virtue of the fact that traction can no longer be attained by the subject bracing himself between two opposite surfaces, and by the volume being far greater than that needed for efficient operation. The data presented on figure 9 will vary for different size test subjects, pressure suit configurations, and the geometry of equipment carried by the astronaut.

Extravehicular locomotion and manipulation tasks.-

Figure 10 presents sequence photographs of some of the self-locomotion and manipulative tasks performed in examining prospective Gemini extravehicular operations using the mockup shown in figure 6.

Sequence (a) figure 10 shows the subject attaching the umbilical line to the standoff preparatory to going to the backside of the Gemini service module. Note that he maintains body position by bracing himself with his feet while using both hands to work. Sequences (b), (c), and (d) show him maneuvering around the back of the service module. In sequence (e) he is preparing the AMU (Astronaut Maneuvering Unit) for donning. Sequences (f) and (g) show him maneuvering into the AMU, while sequence (h) buckling the AMU straps across his chest life support pack.

The single bar foot holds as shown in sequences (a) through (h) with wire toe straps provided unsatisfactory stabilization, in the fore and aft direction, and were changed to the more positive foot holds as shown in sequences (i) through (p).

Sequence (i) shows the subject emerging with the AMU, which was also balanced to neutral buoyancy, attached to his back. Locomotion about the mockup is mainly by hand-arm manipulation, grasping attachments, hand rails, or other protrusions as shown in sequences (h), (i), (j), (k), and (l). During self-locomotion the subject prefers to maintain an upright body position even if such an attitude is not necessary.

Sequence (m) shows the subject floating free of the spacecraft mockup, in a neutrally balanced state. No propulsion capabilities were provided in this simulation. Sequence (n) shows the subject maneuvering to the spacecraft cabin, where he discharges some of his equipment. In sequence (o) he has returned to his station at the back of the service module, where he places his feet in the rigidly mounted stirrups, such that he can maintain body position and be free to work with both hands. In sequence (o) he is shown turning the fuel shutoff valve on the AMU. After releasing the retaining straps he discharges the AMU from his back, sequence (p), then prepares to return to the spacecraft cabin.

The purpose of this series of tests was to examine the pressure suited subject's capabilities to execute the assigned tasks in a weightless environment, determine the suitability of the extravehicular equipment, and develop a more realistic time-line analysis of the work schedule.

These and related tests illustrate that the pressure-suited astronaut may be able to locomote to any position on the exterior of a space vehicle with the use of relatively simple motion or traction aids, eliminating the need for reaction propulsion devices for local tasks.

<u>Maintenance task performance</u>. The neutral buoyancy technique can be used to investigate the astronauts capabilities in performing maintenance tasks in the weightless environment, as illustrated in the sequence photographs of figure 11. During the experiments shown here the pressure suited subject was practicing the D-16 torqueless power tool experiment preparatory to the Gemini 11 flight. Sequence (a) depicts the subject maneuvering into place, while sequence (b) shows him pulling the tool tray out of the side of the spacecraft service module. Sequence (c) shows the subject trying to use the power tool to remove several bolts on the side of the tool tray while maintaining body position by holding onto the tool tray with his left hand. Because of lack of body position control he tumbled out of control each time he tried to do useful work.

During the last four sequences shown on figure 11, the subject used a clip attached to the right knee of the pressure suit which fastened to the hand rail of the spacecraft as depicted in sequence (e). Sequence (f) shows the subject withdrawing the tool tray from the side of the spacecraft. Sequence (g) shows him removing the D-16 tool from the tray and exchanging it with the safety man for a similar tool which was neutrally buoyant. Sequence (h) shows him successfully removing the bolts from the side of the tool tray with the power tool in his right hand while retaining his body position with his left hand on the tray.

In a similar manner he was able to complete the same task with an ordinary ratchet wrench. The simple knee restraint shown here made it possible to complete the assigned maintenance task.

Tests of this nature allow the examination of the astronauts capabilities in real time without interruption, allow assessment of hardware interfaces, and serve to train the astronaut in the procedures required in space. The task in figure 11 illustrates the necessity for body restraints or attachments to the spacecraft if the hands are to be free to perform maintenance tasks, and the necessity to examine procedures in advance of flight tests.

Local personnel rescue. The sequence photographs of figure 12 illustrate one of several tests performed to examine the feasibility of rescuing a disabled extravehicular astronaut into a spacecraft airlock. Two pressure-suited neutrally buoyant subjects were used, a passive subject on the exterior and an active subject on the interior of the airlock configuration (fig. 5), attempting to retrieve the passive subject as quickly as possible.

Sequence (a) shows the passive subject on the end of a safety line being pulled to the airlock hatch. Sequences (b), (c), (d), and (e) show the steps required to move the subject into the hatch opening. Because the passive subject could not be pulled through the hatch opening by the safety line, the active subject grasped the neck ring of the passive subject to move him through the hatch, sequences (f), (g), and (h).

In sequence (i) the active subject is shown climbing over the passive subject in order to further move him into the airlock. During sequence (j) he was forced to grasp the passive subject's foot to maneuver him entirely into the airlock. Sequence (k) shows him moving the passive subject's feet aside in order to close the inward opening hatch door. Sequence (l) shows him closing the hatch door.

The tests shown on figure (12) are explanatory in nature, however, they illustrate how the water immersion simulation technique can be used to examine and further develop prospective rescue procedures.

CONCLUDING REMARKS

The water immersion, zero gravity simulation technique, while limited by drag and damping forces, allows us to approximate perceptually equivalent real-life extravehicular problems in space. It is presently being used to examine work loads and schedules, the adequacy of extravehicular equipment, and as a training aid in support of the Gemini and Apollo flight programs. Up to this time two of the astronauts have actively participated in the water immersion simulation of Gemini extravehicular operations to further evaluate the applicability of the technique and for procedural training. The results of their participation have not been fully determined at this time.

Related work is in progress to measure the astronaut's energy expenditure by metabolic means during water immersion simulation of typical extravehicular tasks in pressurized suits. These measurements will be compared with those obtained from similar tasks by other means of simulation and eventually compared with measurements made in space.

The water immersion technique will be a useful manned task simulation tool for additional human factors studies. These will include the assessment of the extravehicular astronaut's capabilities to perform additional maintenance and assembly functions, perform both routine and emergency procedures, and complete logistic support work schedules. Further refinement of the technique will make it possible to quantitatively measure the performance and proficiency of the astronaut in man-machine systems and predict his physiological and psychological responses under simulated working conditions.

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BIOGRAPHY

Otto F. Trout, Jr. (Water Immersion Reduced Gravity Simulation) is an Aerospace Technologist in the Applied Material and Physics Division of National Aeronautics and Space Administration's Langley Research Center, Hampton, Virginia. After receiving his B.S. degree from College of William and Mary in 1948 he has worked continuously for NASA (formerly NACA) on propulsion system development until 1955, as project engineer and supervisor on the development of high temperature reentry testing facilities until 1962, and to the present as project engineer on the research and development of advanced spacecraft systems. As a result of his study of the human-engineering requirements for spacecraft airlock systems and extravehicular equipment he initiated and supervised the development of water immersion zero-gravity simulation by subjects in pressurized suits to obtain unavailable human factors data, both inhouse and on contract. His publications include Water Immersion Reduced Gravity Simulation and A Water Immersion Technique for the Study of a Pressure-Suited Subject Under Balanced Gravity Conditions with H. L. Loats and S. G. Mattingly.

William J. Bruchey, Jr. (Water Immersion Reduced Gravity Simulation) is a project engineer at Environmental Research Associates, Randallstown, Maryland. After receiving his B.S. degree in physics from the University of Maryland in 1964 and serving on active duty in the U.S. Army, he was employed in 1965 by Environmental Research Associates. He has served as project engineer in the water immersion simulation on Phase III of Contract NAS1-4059, "A Study of Astronaut Performance Through Airlocks and Passageways," and in simulations of the extravehicular tasks on the Gemini programs. Currently he is involved with a simulation program to evaluate human factors design of the airlock module to be used in the Apollo Applications Program.

Publications include Water Immersion Reduced Gravity Simulation and Phase III report on Contract NAS1-4059, A Study of Astronaut Performance Through Airlocks and Passageways.

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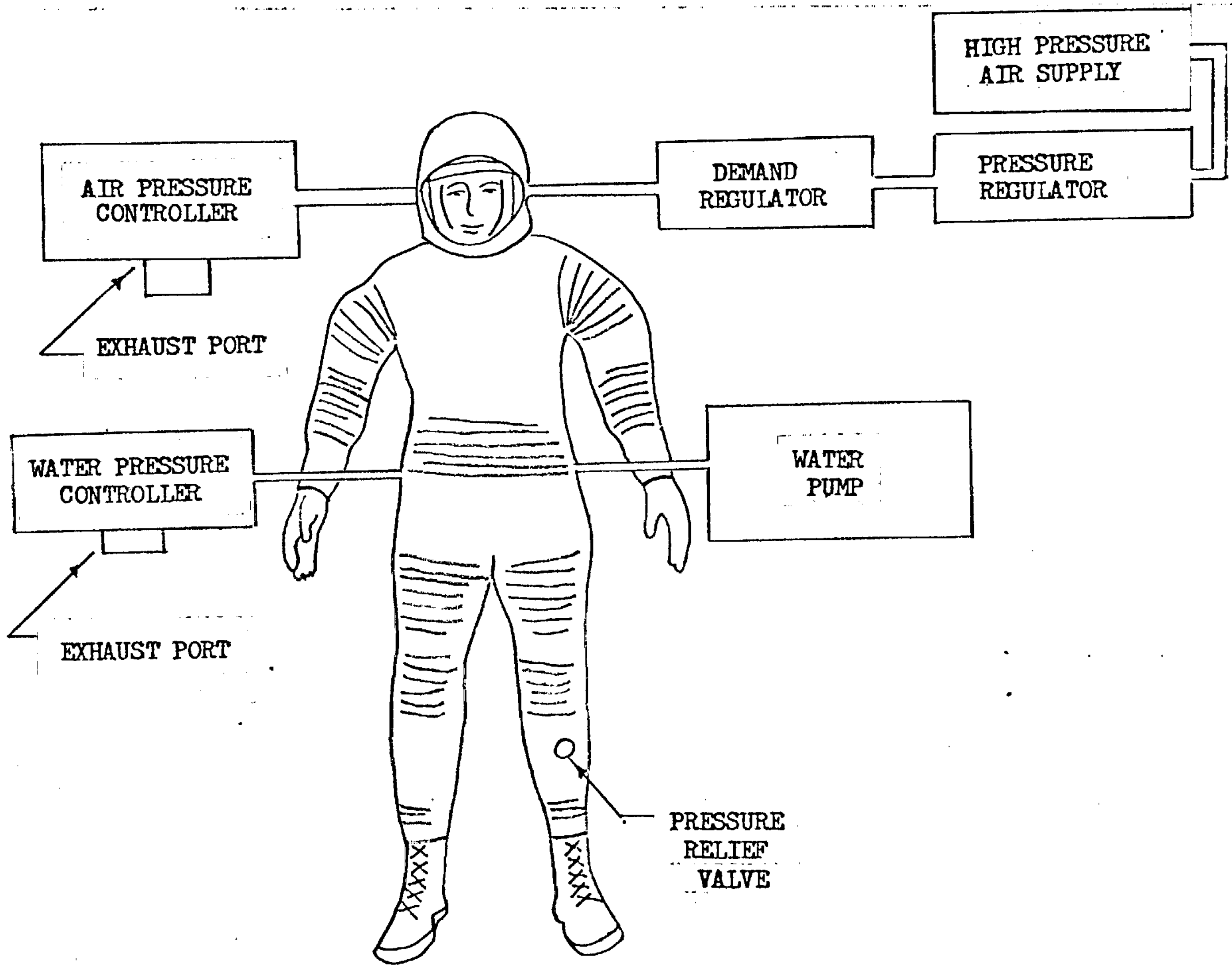

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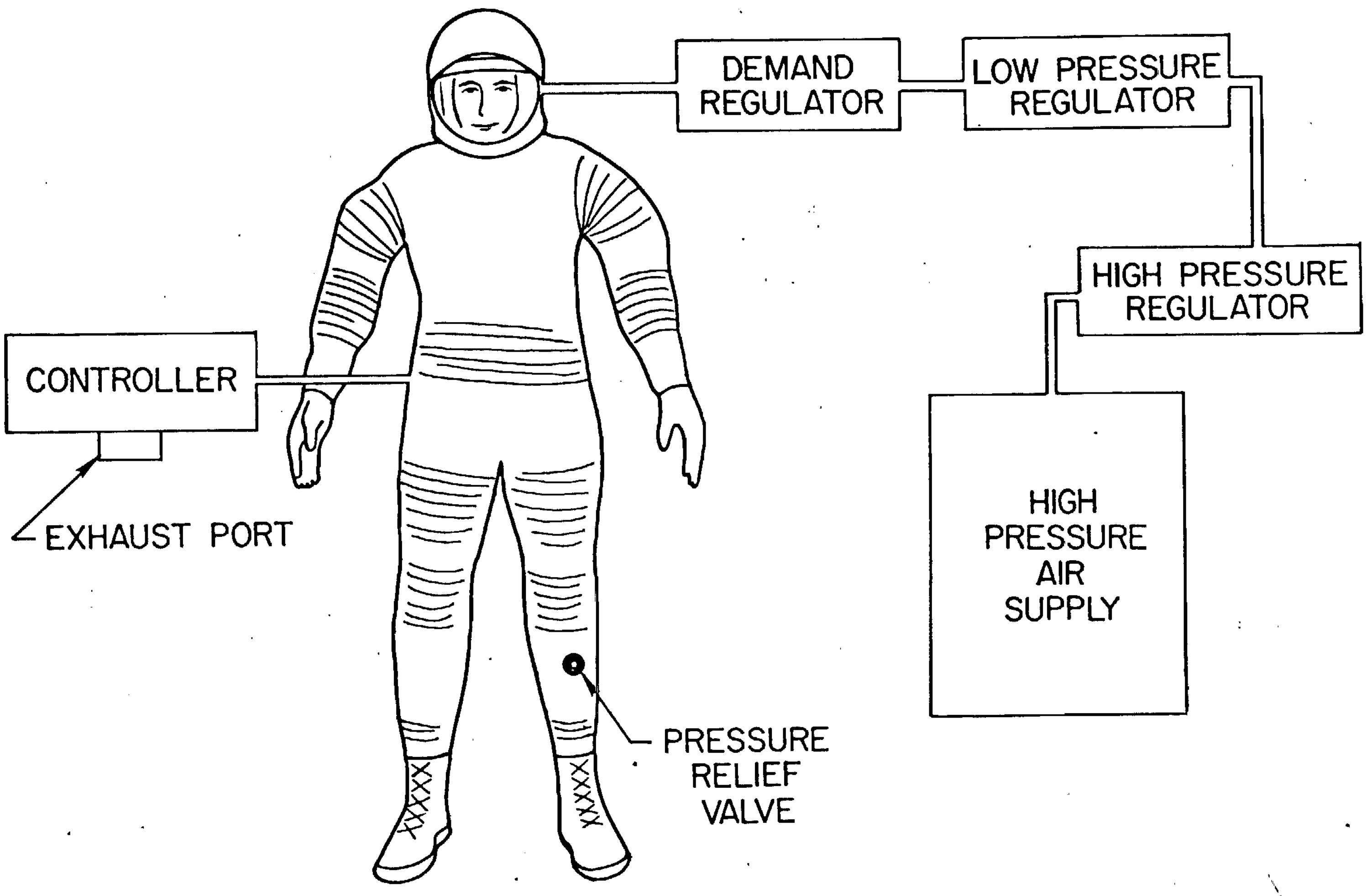

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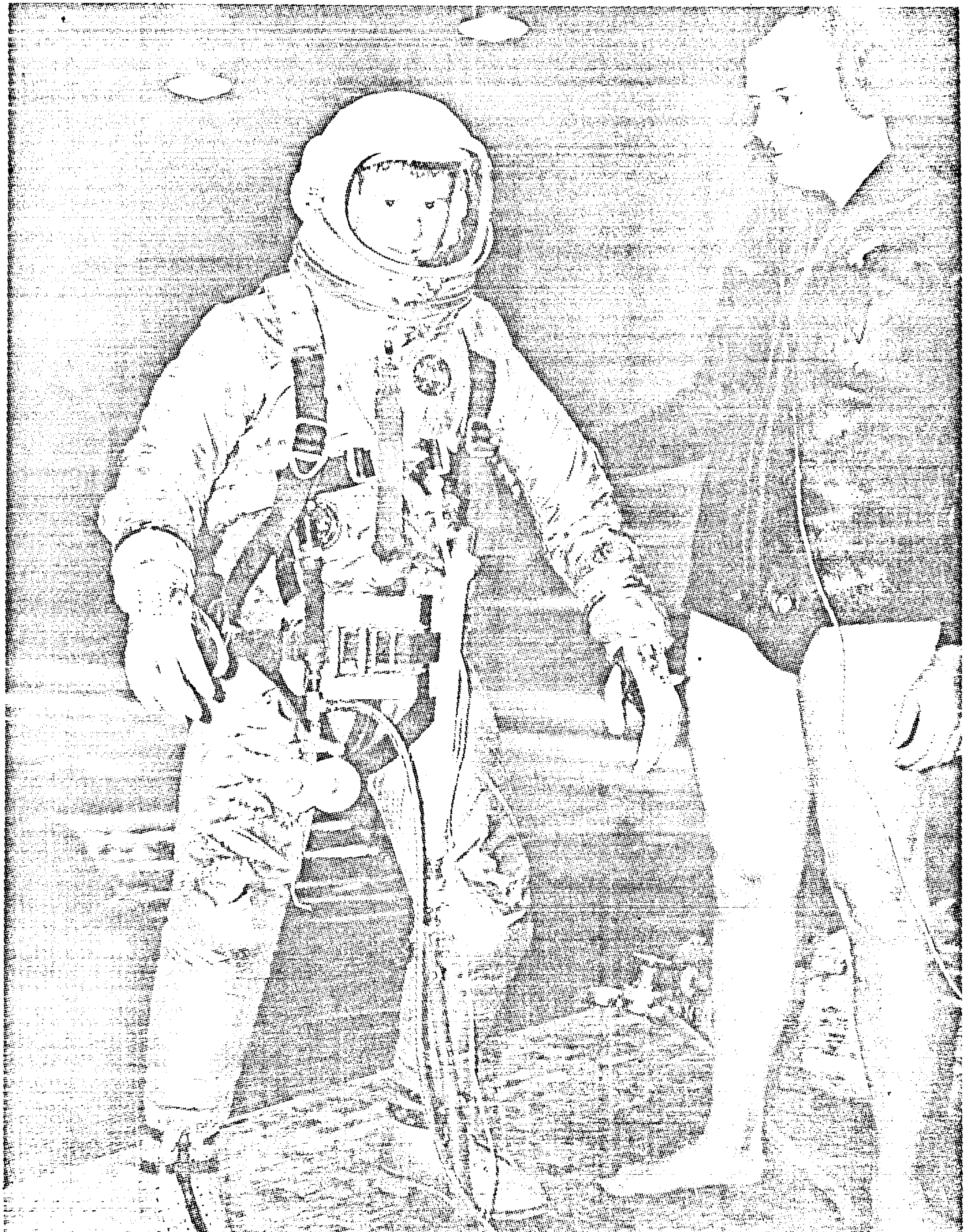

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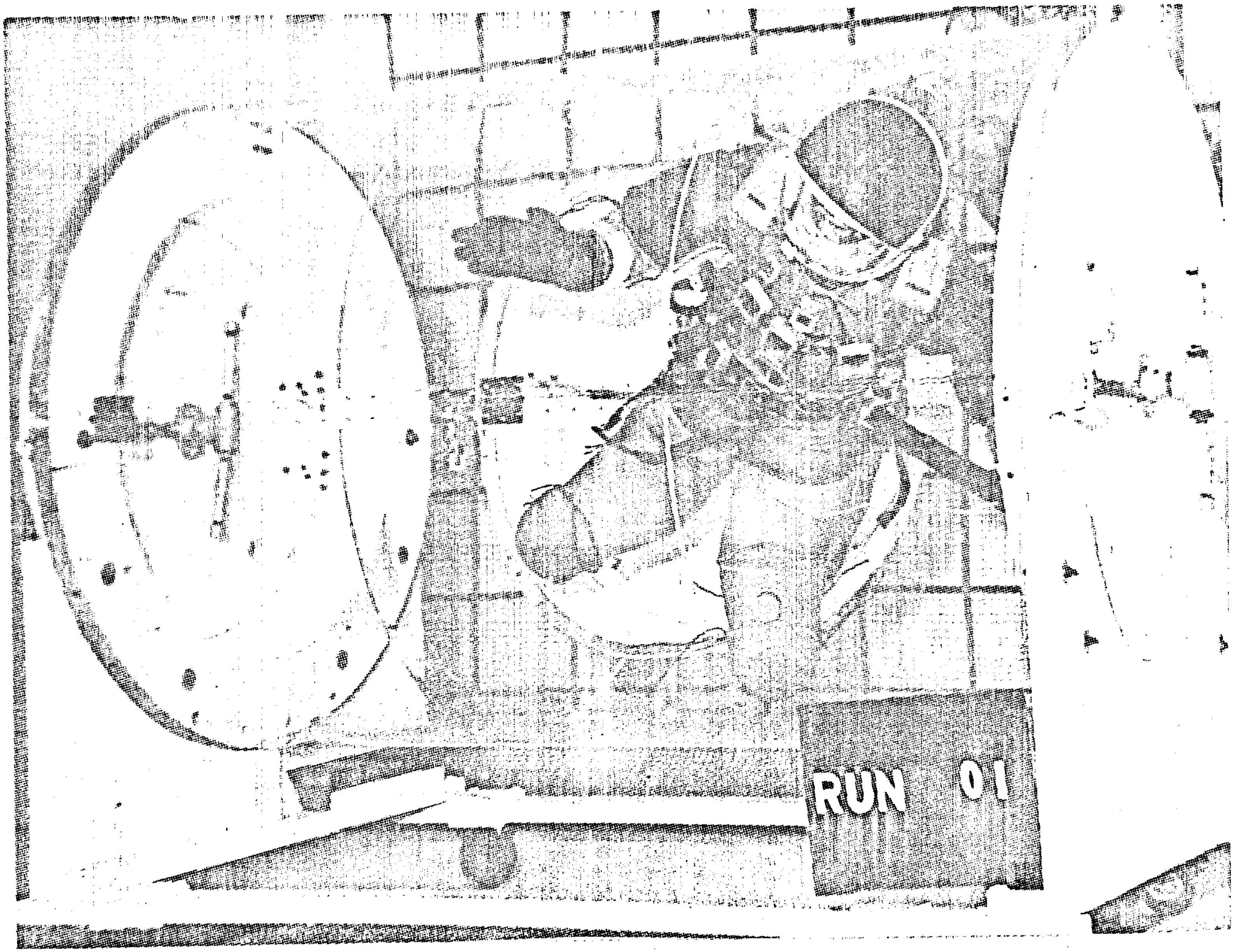

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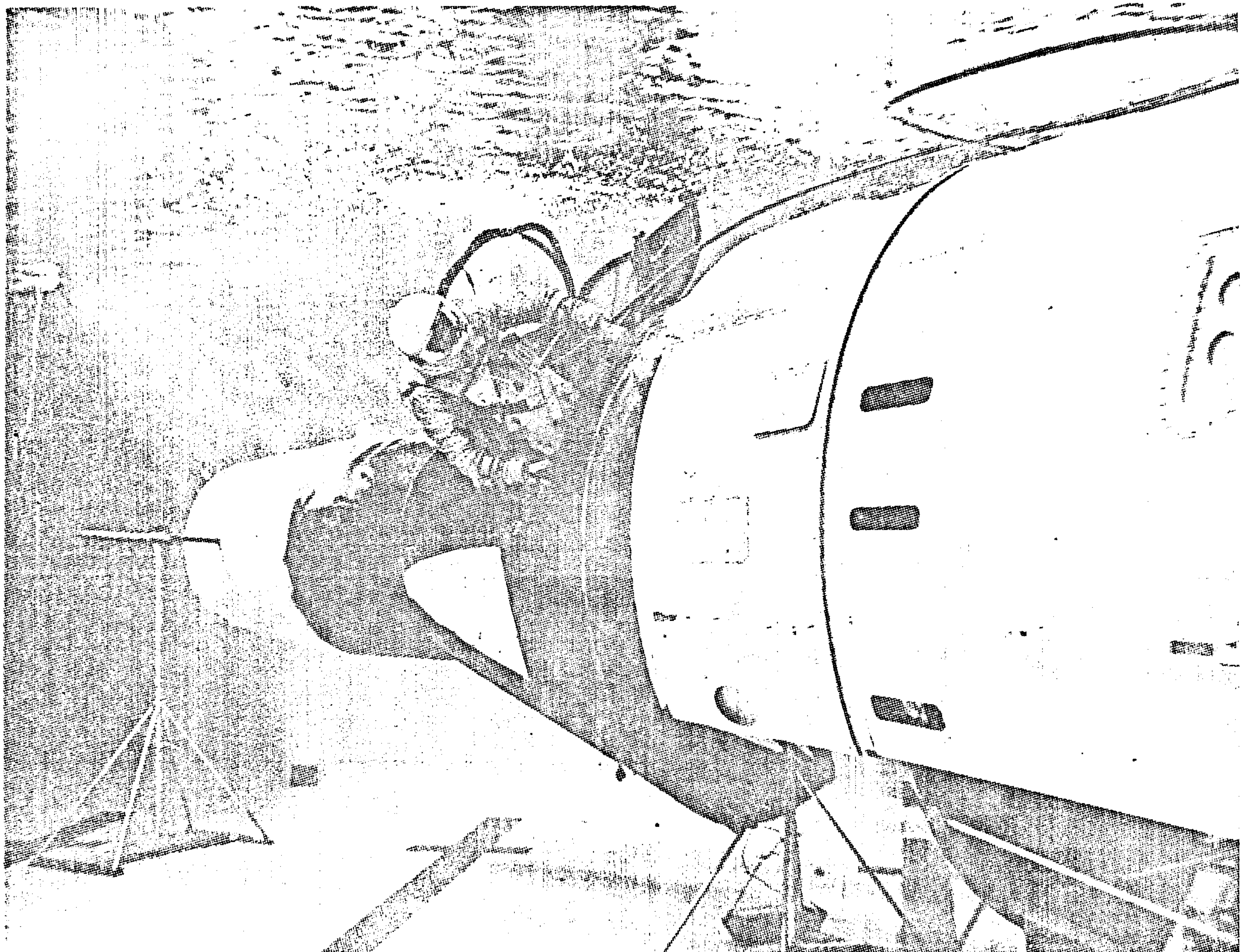

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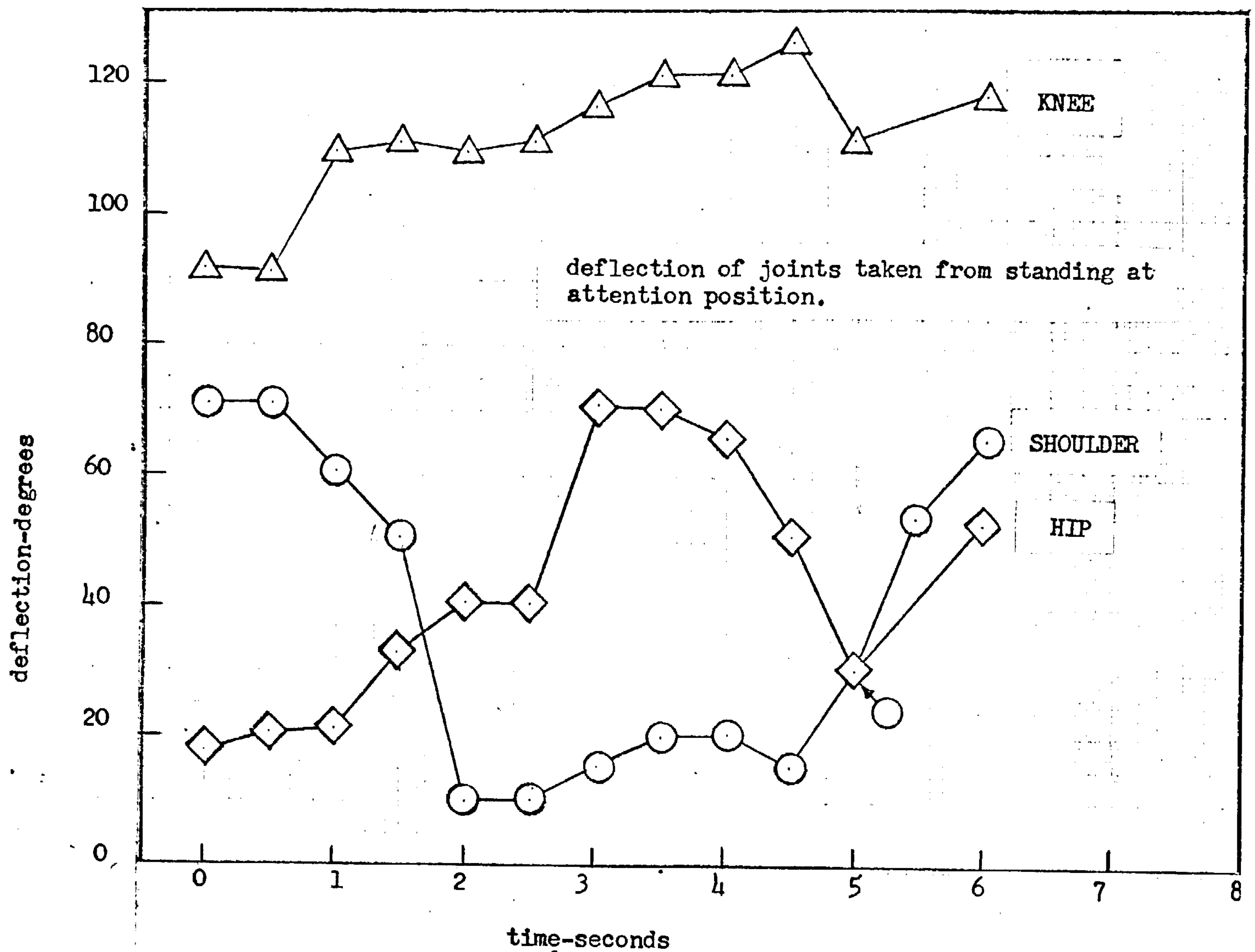

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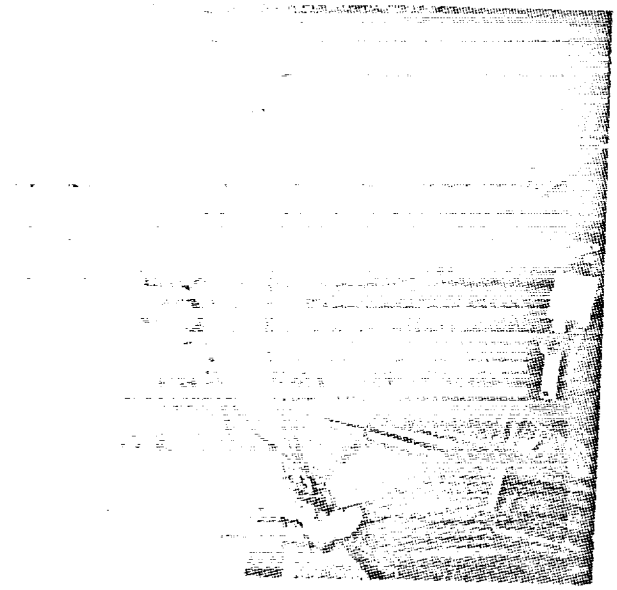

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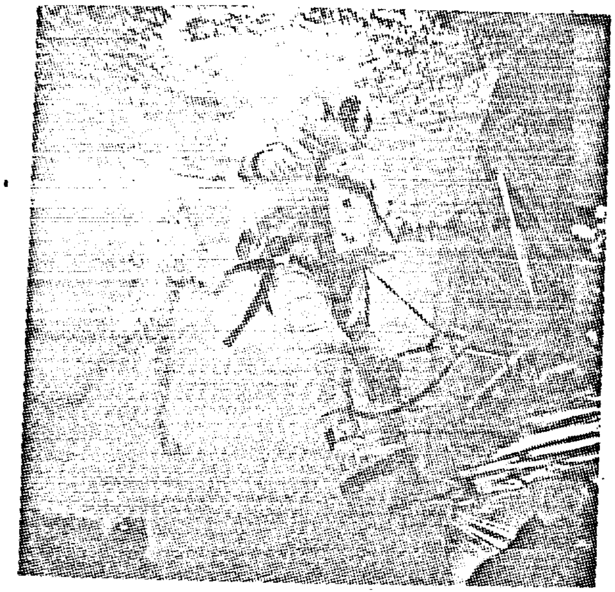

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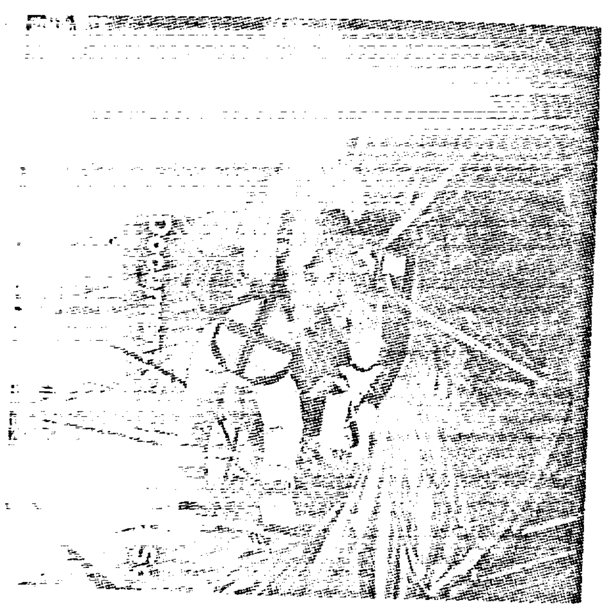

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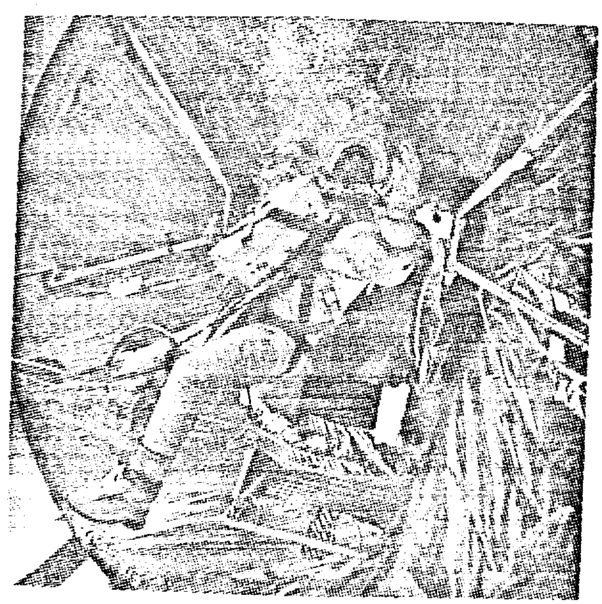

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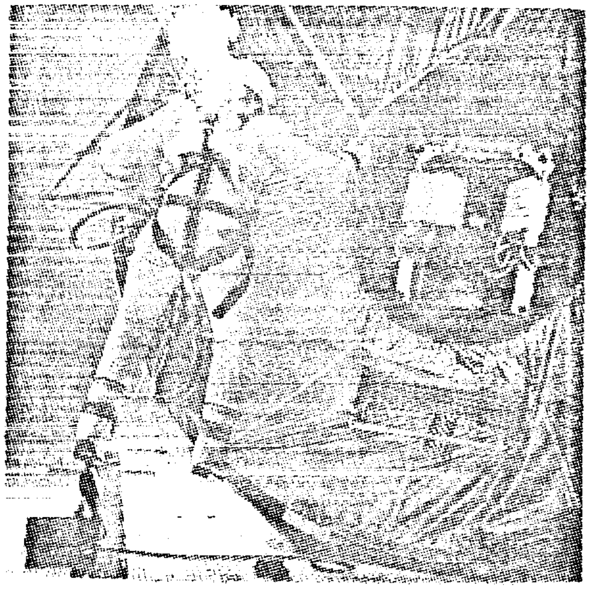

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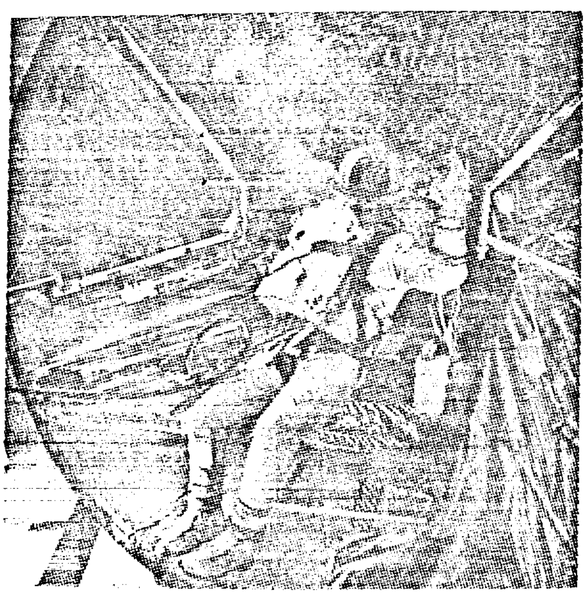

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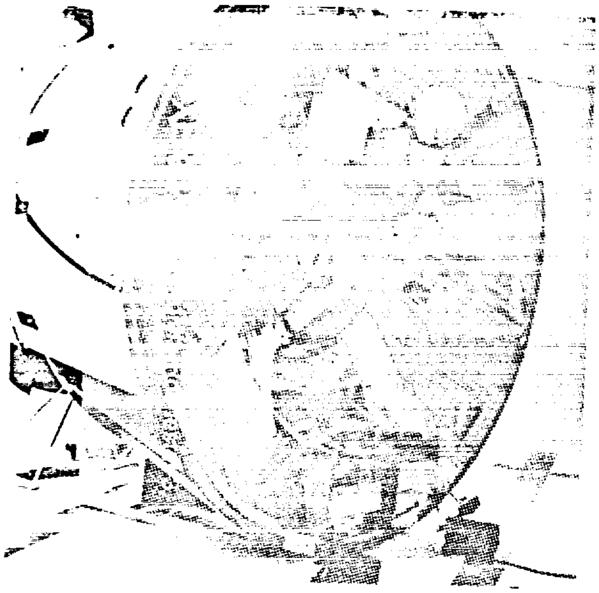

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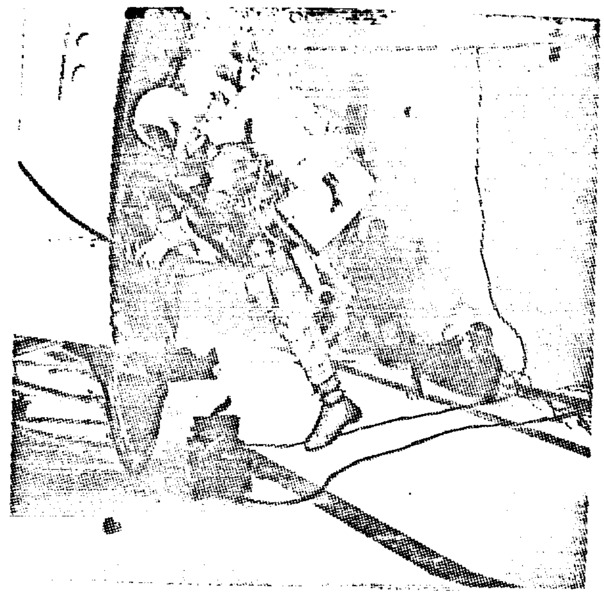

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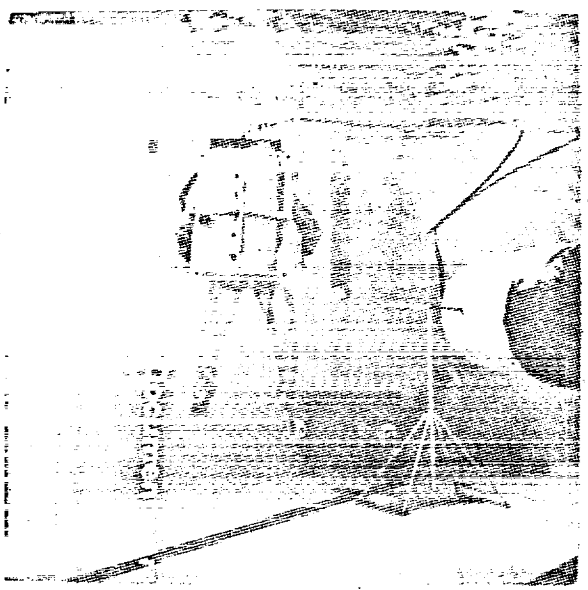

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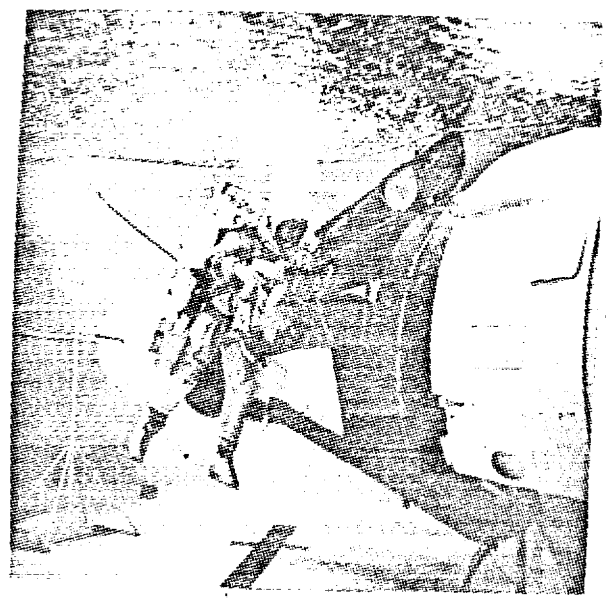

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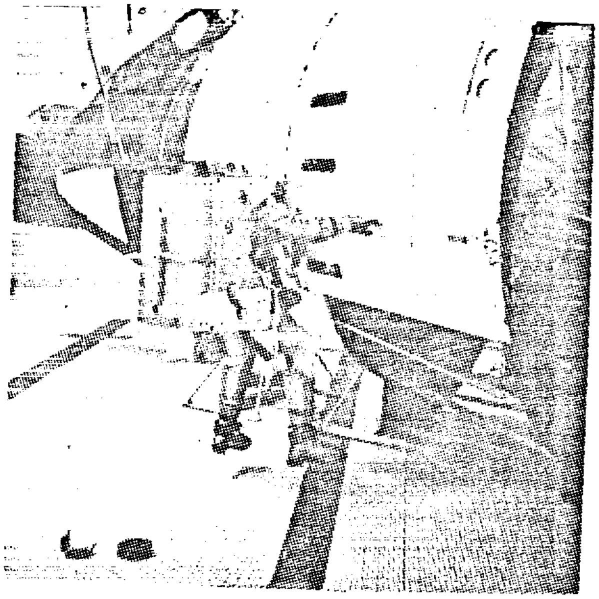

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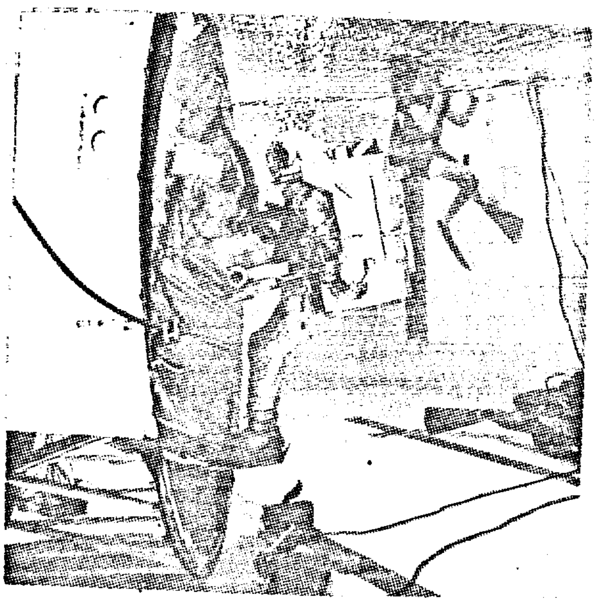

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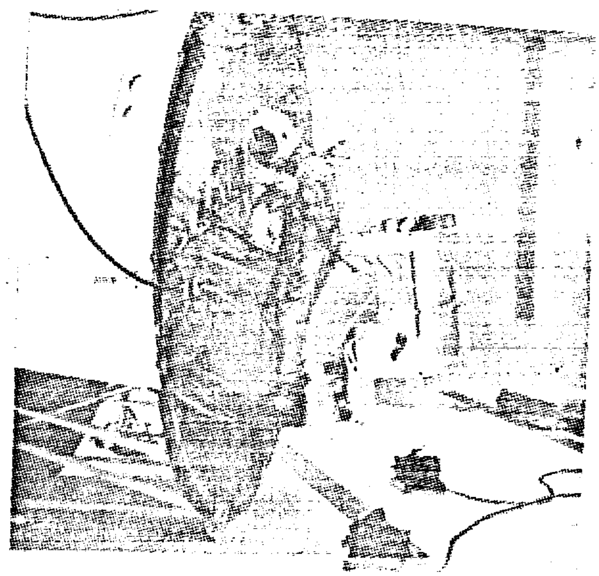

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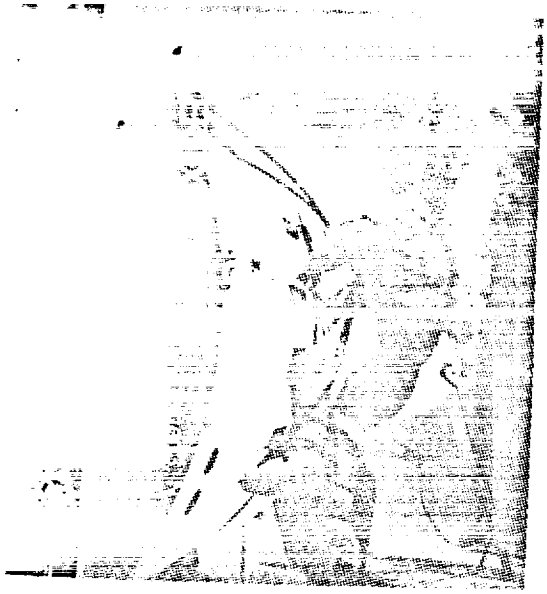

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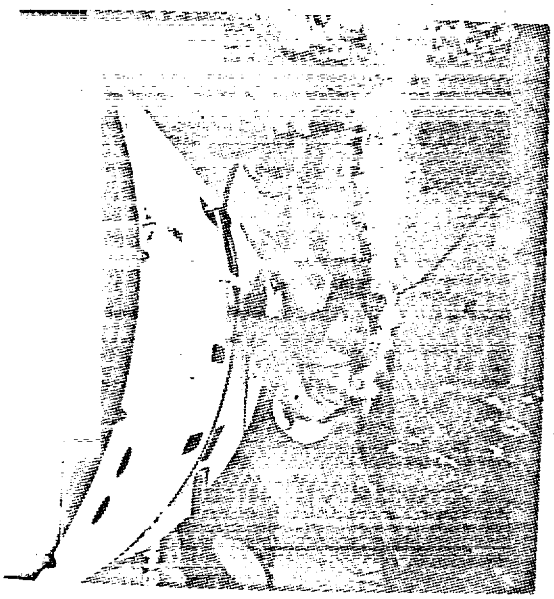

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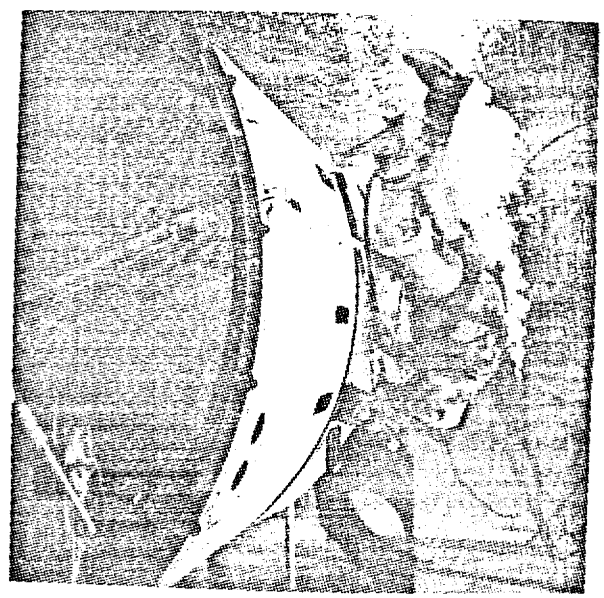

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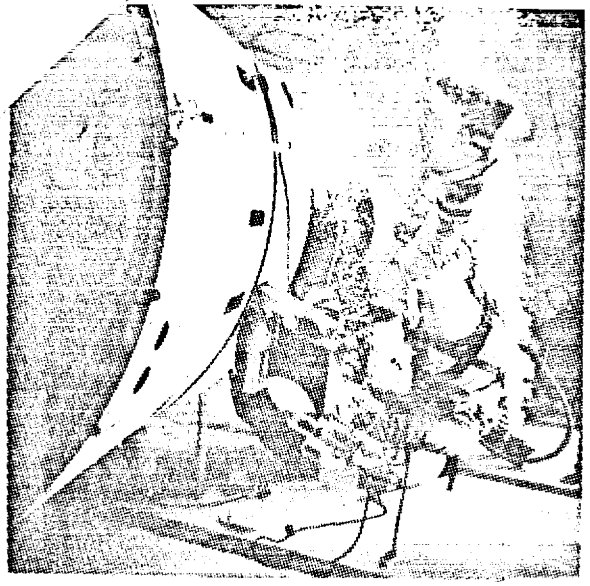

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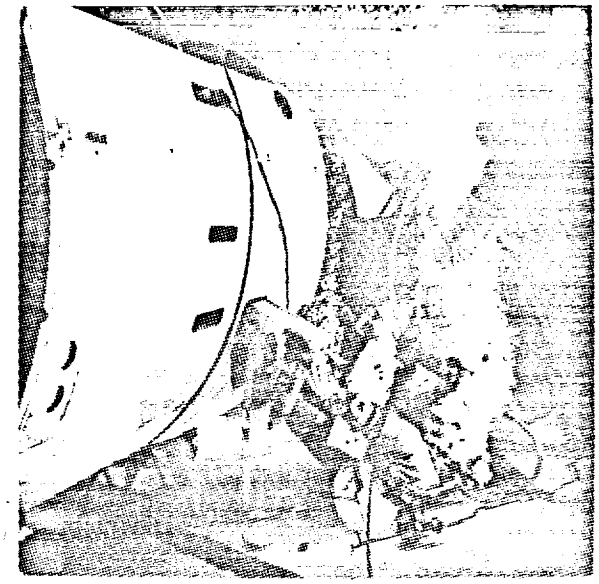

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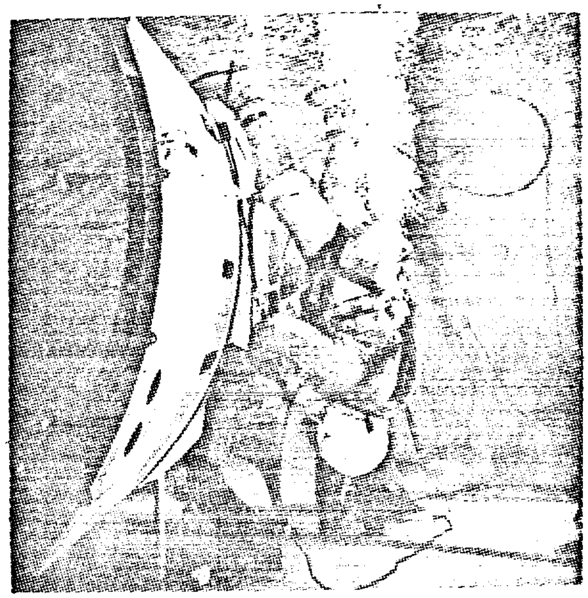

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